Improvements to the Turbulence in Wind-Driven Surface Currents

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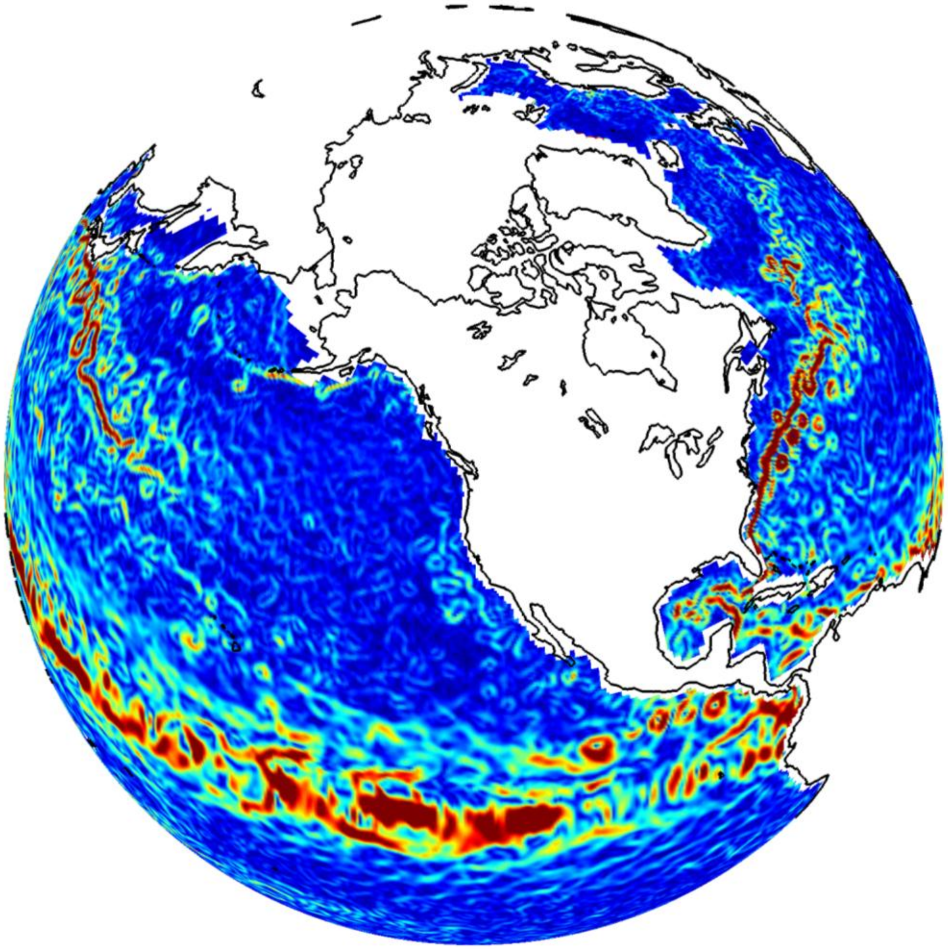
- OSCAR surface currents wind-driven components
  - Time-dependent
  - Vertical variation

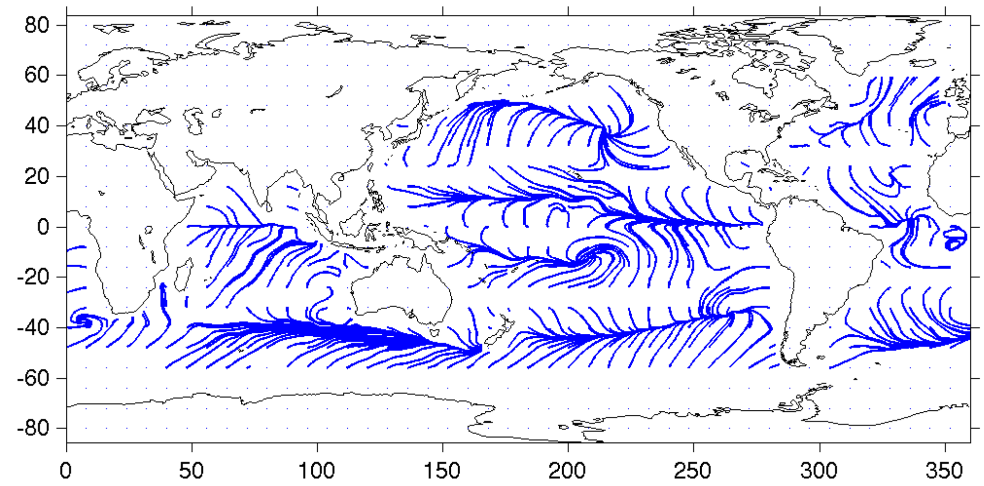


OSCAR Surface currents from satellite fields

- Ocean Surface Currents Analyses-Realtime processing system (OSCAR) is a satellite-derived global surface current database provided in near-real time based on geostrophy, Ekman dynamics, and thermal wind, assuming quasi-steady dynamics
- Hosted at the PO DAAC, http://podaac.jpl.nasa.gov/
- Surface currents are calculated from SSH, ocean vector winds, SST (note: all are gridded fields)
    - **SSH**: geostrophic term is computed from the gradient of ocean surface topography fields (merged gridded AVISO/CLS: Jason-1,-2, T/P, Envisat, GFO, ERS-1,-2)
    - **WIND**: wind-driven velocity is computed from an Ekman/Stommel formulation with variable eddy viscosity using QuikSCAT vector winds (FSU/COAPS) and NCEP winds, replaced by ERA-I winds – currently investigating CCMP winds
    - **SST**: thermal wind term using Reynolds OI SST data (looking at higher resolution products to capture fronts).

Wind Driven Mixed Layer

- Improve the performance of OSCAR for wind-driven motions
    - We're capturing long-term dynamics
    - Typically poor correlations with drifters for daily wind-driven motions



- Better understanding of the transfer of momentum from the atmosphere to the ocean
    - Depth of penetration of direct wind-driven motions
    - Loss of inertial energy to deep

OSCAR model

OSCAR model

Quasi-steady linear flow in a surface layer with turbulent mixing parameterized by a constant in the vertical eddy viscosity. Frontal model: buoyancy force θ is a function of SST horizontal gradients only. Surface layer velocity $\bar{\mathbf{U}}$ by averaging over the top 30m.

$$
\begin{aligned}
if\mathbf{u} &= -\frac{1}{\rho}\nabla p + \frac{\partial \tau}{\partial z} \\
\tau &= K\frac{\partial \mathbf{u}}{\partial z}.
\end{aligned}
$$

Stommel model boundary conditions

$$
\begin{aligned}
\frac{\partial \mathbf{u}}{\partial z}(z=0) &= \frac{1}{\rho_0 K}\tau_0 \\
\frac{\partial \mathbf{u}}{\partial z}(z=-H) &= 0
\end{aligned}
$$

where: $\mathbf{u} = u + iv$, τ_0 is surface wind stress, $H = 125m$, and K is a vertical eddy viscosity, calculated as a function of wind

$$K = a\left(\frac{|\mathbf{W}|}{W_0}\right)^b.$$

Optimal choice for a in OSCAR blends from 8×10^{-5} m^{2}s^{-1}, $b = 2.2$ at the equator as in Santiago-Mandujano & Firing (JPO 1990), to 2.85×10^{-4} m^{2}s^{-1}, $b = 2$ for the global value.

Vertical Variation, quasi-steady

Rather than solve for the shear, Cronin and Kessler (JPO 2009) solved for stress, using the Generalized Ekman boundary conditions and a vertically varying eddy viscosity which decays with depth so that the stress becomes zero at depth H, while the shear can remain nonzero.

Generalized Ekman boundary conditions

$$\tau(z=0) = \tau_0$$
$$\tau(z=-H) = K(z)\frac{\partial \mathbf{U}}{\partial z}(z=-H) = 0.$$

where: $K = A\exp(z/D) - B$, $D = 125$m and $K = 16e-03\ \mathrm{m}^2\mathrm{s}^{-1}$ at 10m and zero at 250m.

Time dependence and vertical variation

Linear Unsteady Ekman

$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = \frac{1}{\rho}\frac{\partial \tau(t,z)}{\partial z}$$

One option to parameterize the turbulence is the simplest: Rayleigh drag. Damped slab model = linear time-dependent Ekman solution, damping parameter r. Equations of motion, averaged over the mixed layer, depth MLD:

$$\frac{d\mathbf{U}(t)}{dt} + if\mathbf{U}(t) = \frac{\tau(t)}{\rho MLD} - r\mathbf{U}(t)$$

Alternately, parameterize turbulence as an eddy viscosity, $K(z)$:

$$\tau = -K(z)\frac{\partial \mathbf{u}}{\partial z}$$

$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = \frac{\partial}{\partial z}(K(z)\frac{\partial \mathbf{u}(t,z)}{\partial t})$$

Time dependence and vertically varying Eddy viscosity

$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = \frac{\partial}{\partial z}(K(z)\frac{\partial \mathbf{u}(t,z)}{\partial t})$$

Elipot and Gille (Ocean Science, 2009), solved in Fourier space (very fast to calculate) using 3 simple forms of eddy viscosity:

$$K(z) = K0$$

$$K(z) = K1 * z$$

$$K(z) = K0 + K1 * z$$

and 3 boundary conditions:

$$u(z- > infinity) = 0$$

$$u(z = -H) = 0$$

$$\frac{\partial u(z = -H)}{\partial z} = 0.$$

The Models Shown Here

OSCAR: $K(z) = K0$, no $\frac{\partial}{\partial t}$

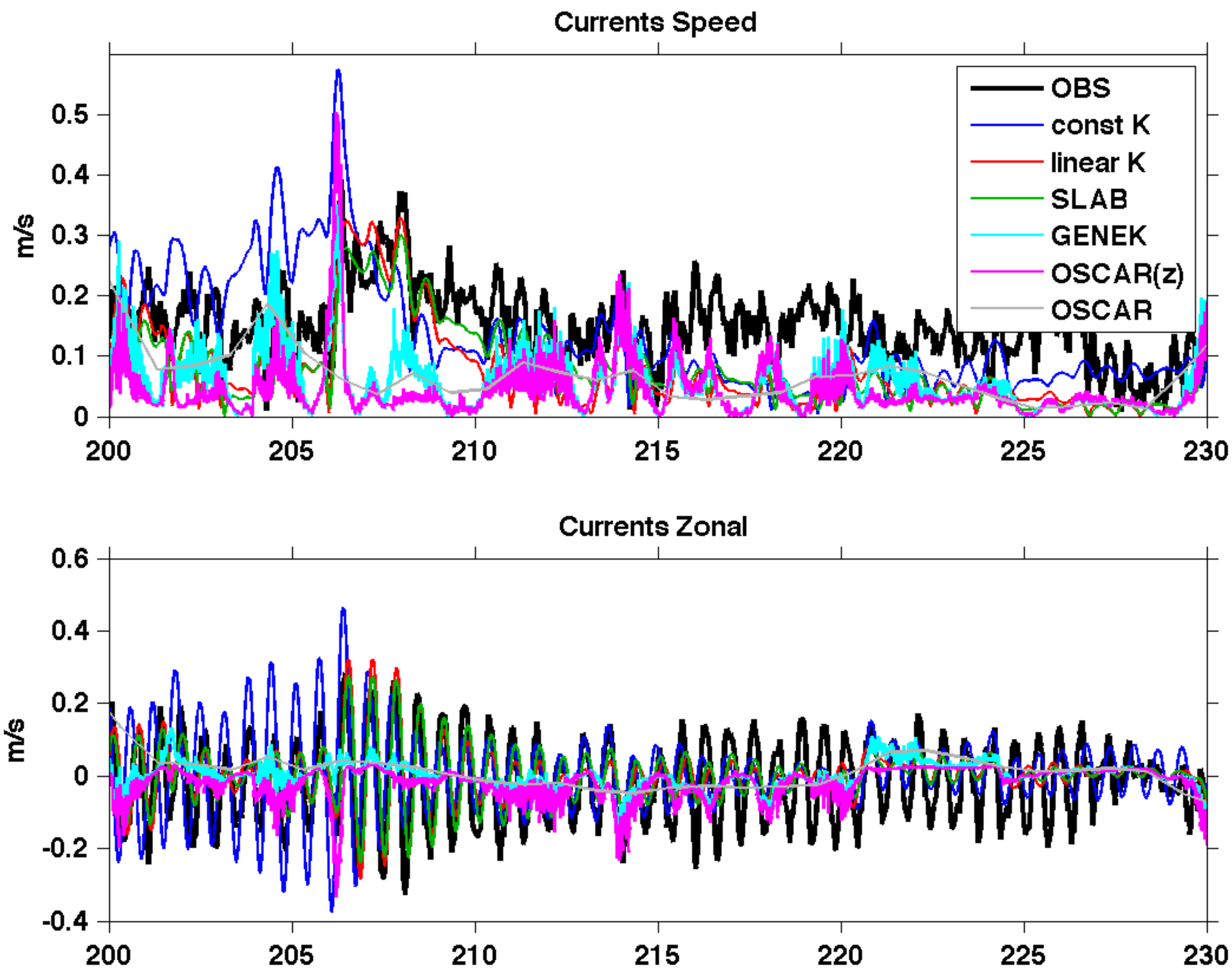
GENEK: $K(z) = A\exp(z/D) - B$, no $\frac{\partial}{\partial t}$

SLAB: r, constant properties in mixed layer, $\frac{\partial}{\partial t}$ term

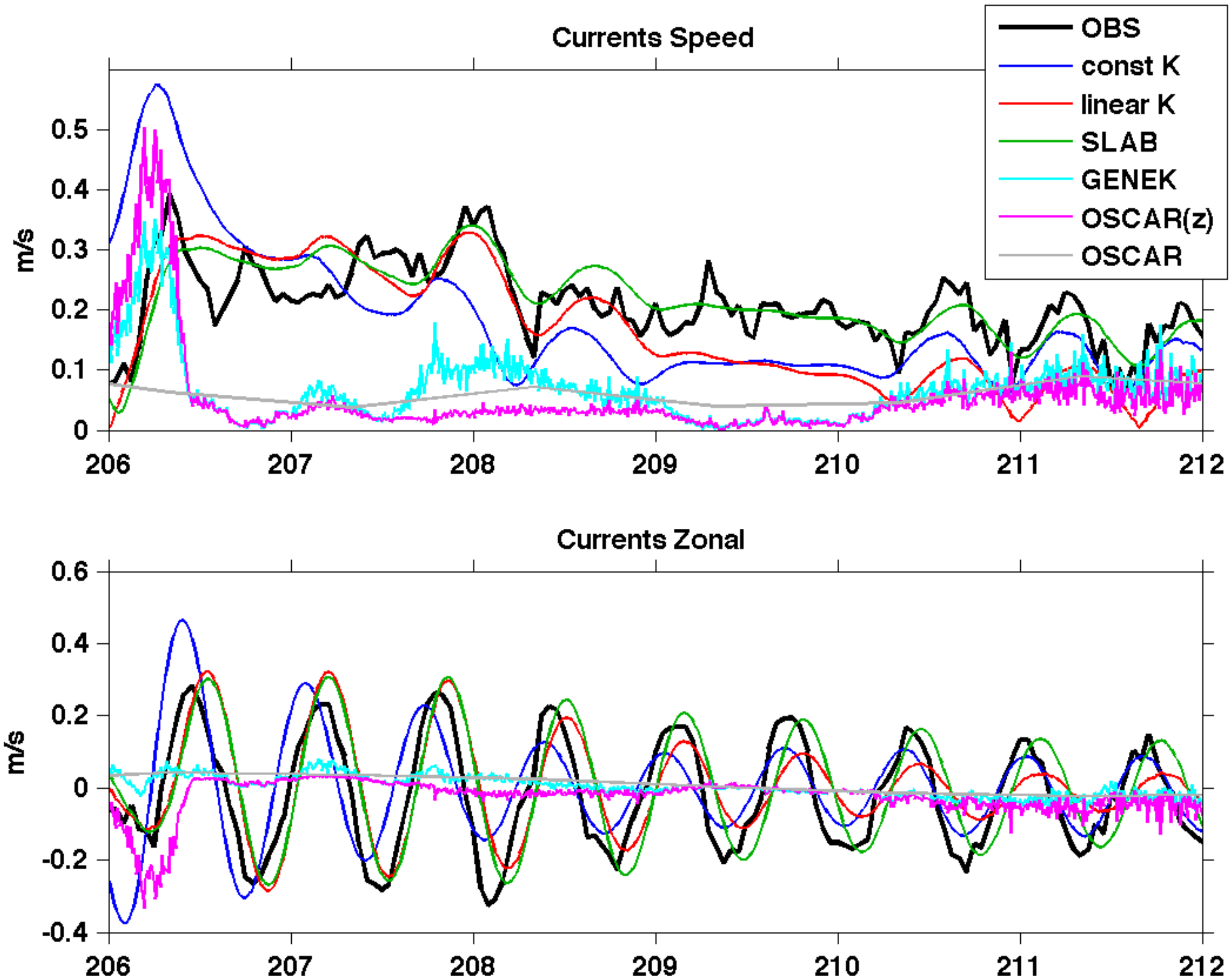
CONSTANTK: $K(z) = K0$, $\frac{\partial}{\partial t}$

LINEARK: $K(z) = K0 + K1z$, $\frac{\partial}{\partial t}$

Model Performance for K(z) and d/dt



Model Performance for K(z) and d/dt

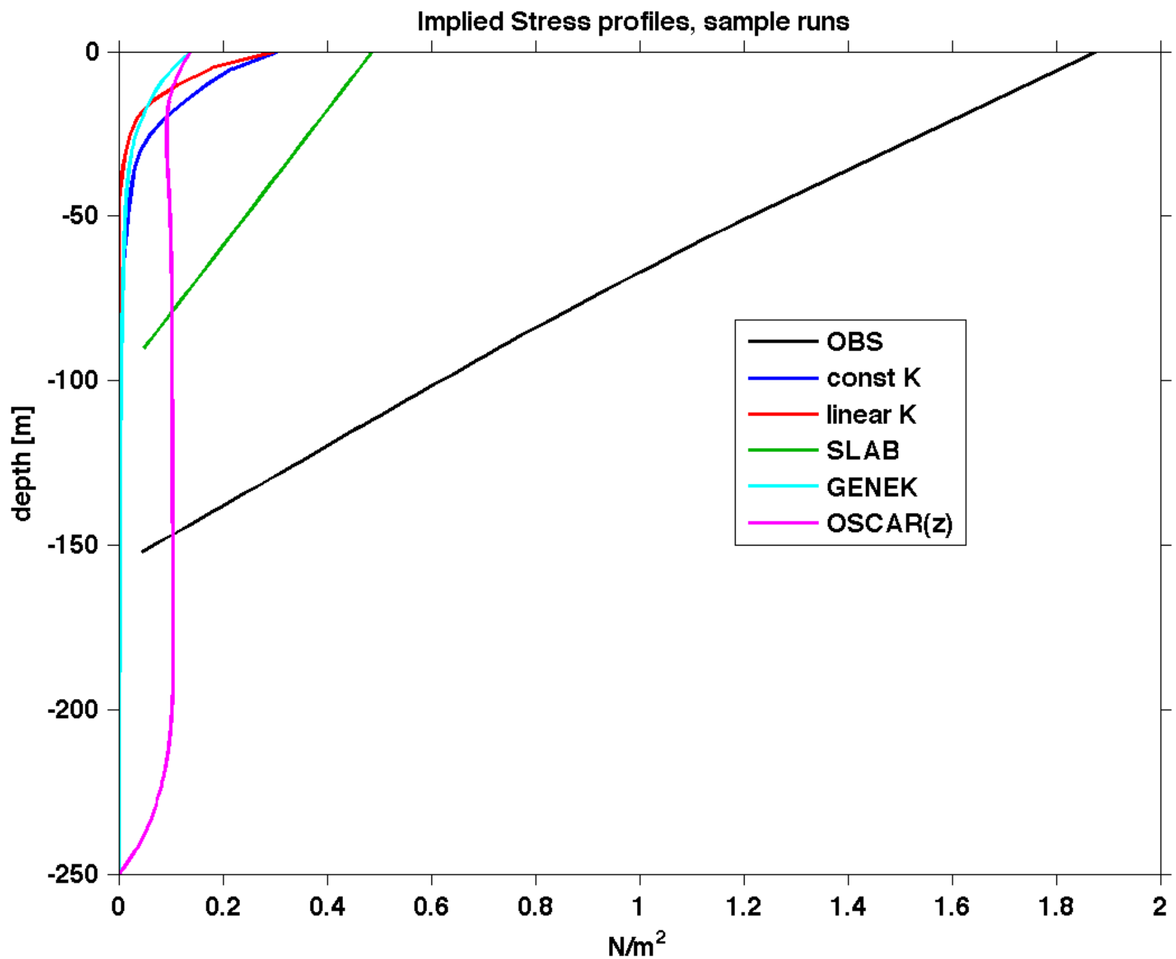


Eddy viscosity K(z) performance

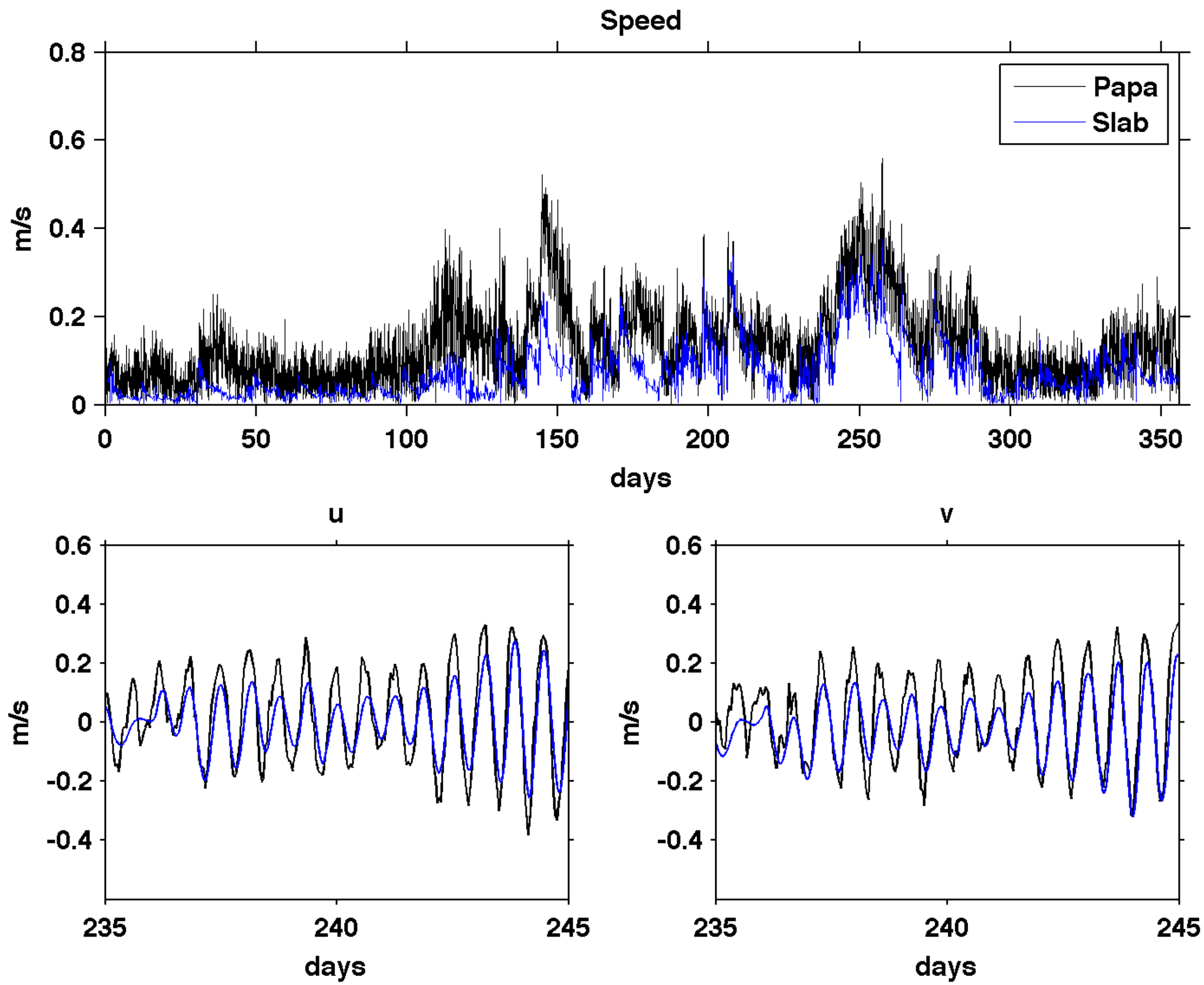
- Calculate the stress on the mixed layer, assuming unsteady Ekman, given velocity profiles

$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = -\frac{1}{\rho}\frac{\partial \tau(t,z)}{\partial z}$$

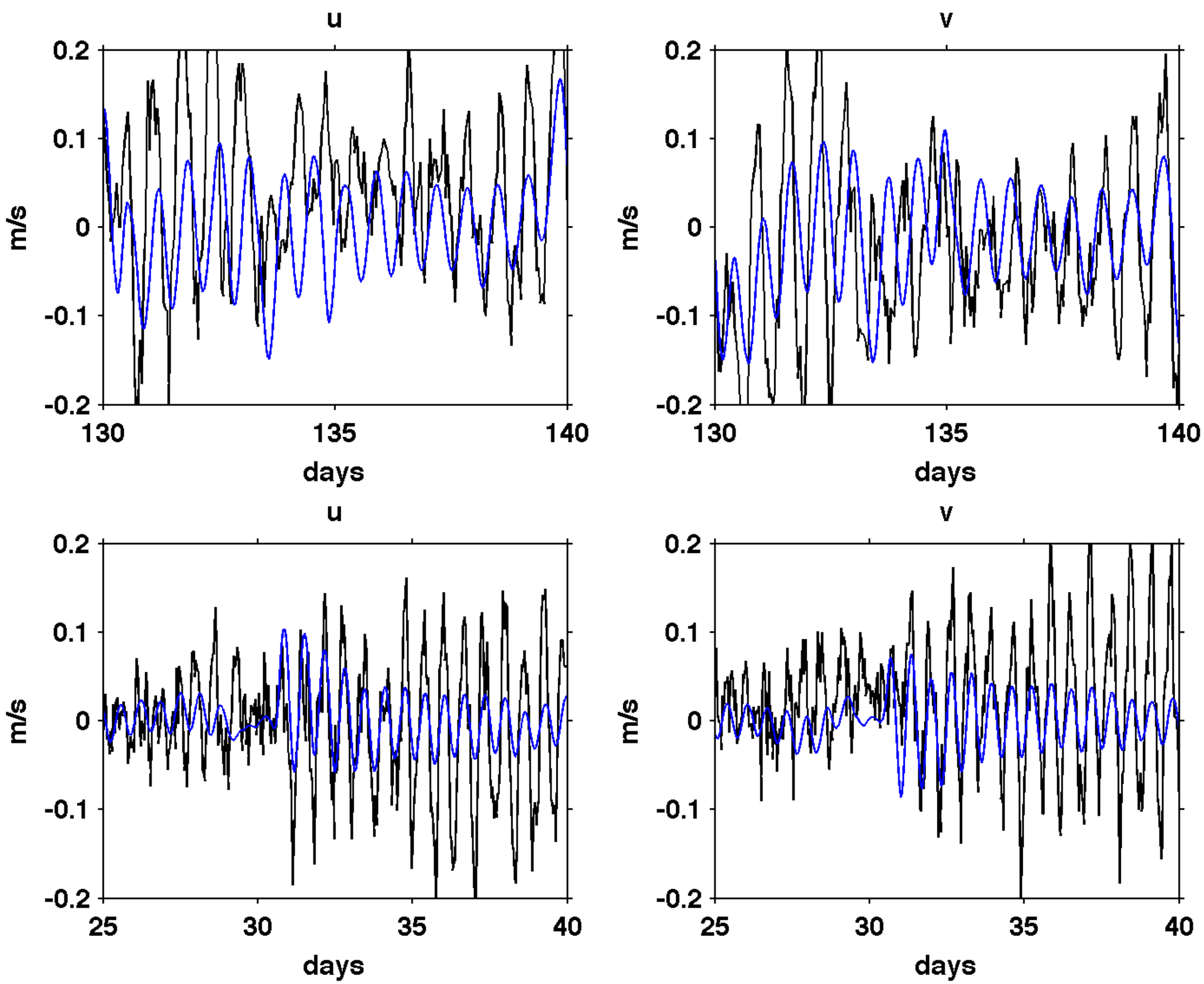
- Averaged over a year
- Big difference in models
- GENEK and OSCAR values match actual wind stress values at surface, by definition
- Observations look slab-like, although prob not all of geostrophic component has been removed



Slab Model Results with 10 minute Papa Winds



Slab Model Results with 10 minute Papa Winds

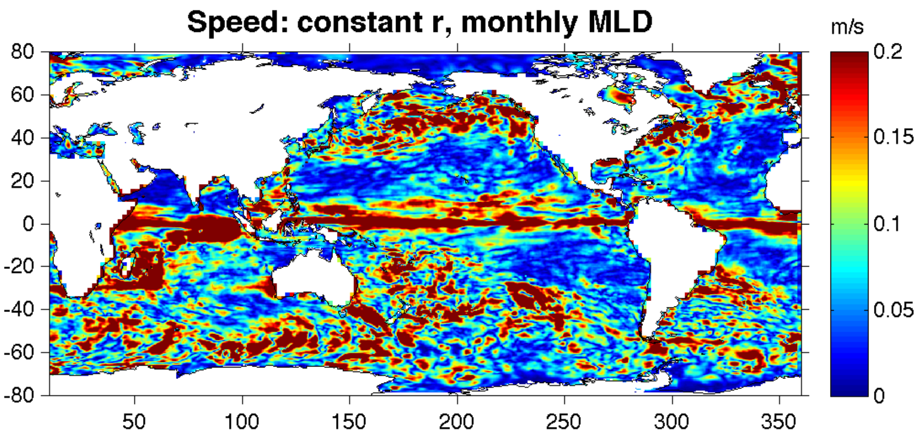


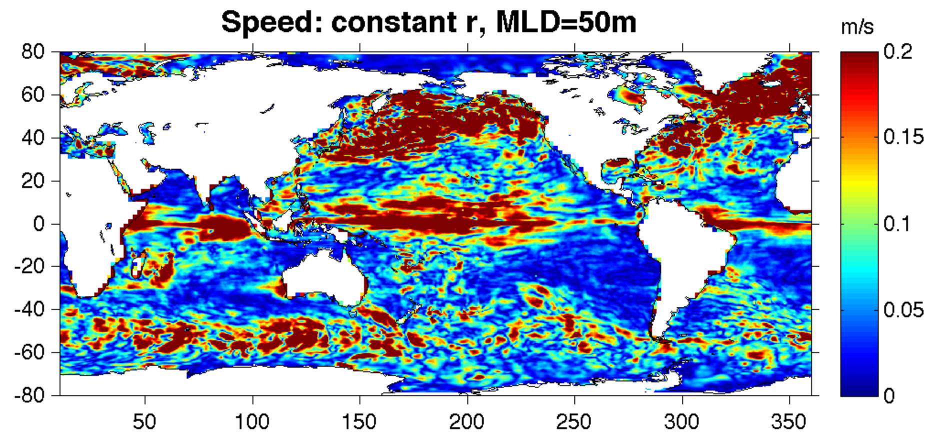
Look at Slab

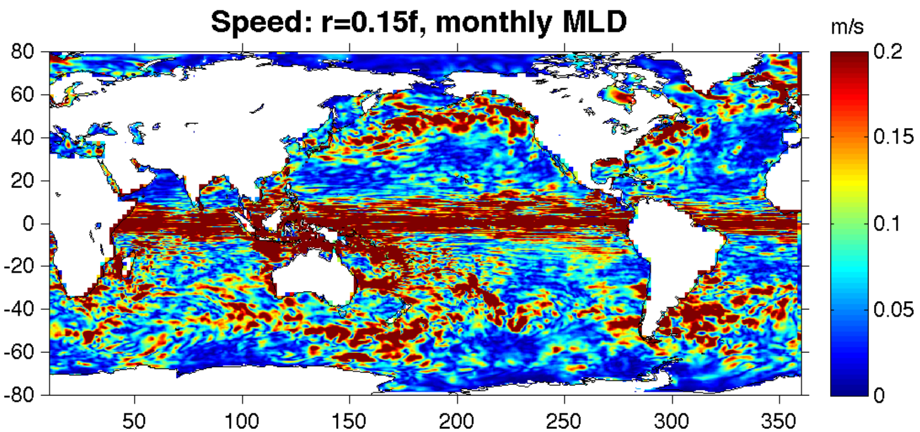
- Slab performed well at Papa, look global
- 3 test cases for the year 2008, CCMP winds

  - 1) Rayleigh damping optimized for Papa performance, using mixed layer depths from monthly climatology
  - 2) Rayleigh damping optimized for Papa performance, using mixed layer depth =50m
  - 3) Rayleigh damping following Alford (2003 JPO) r=0.15f, using mixed layer depths from monthly climatology

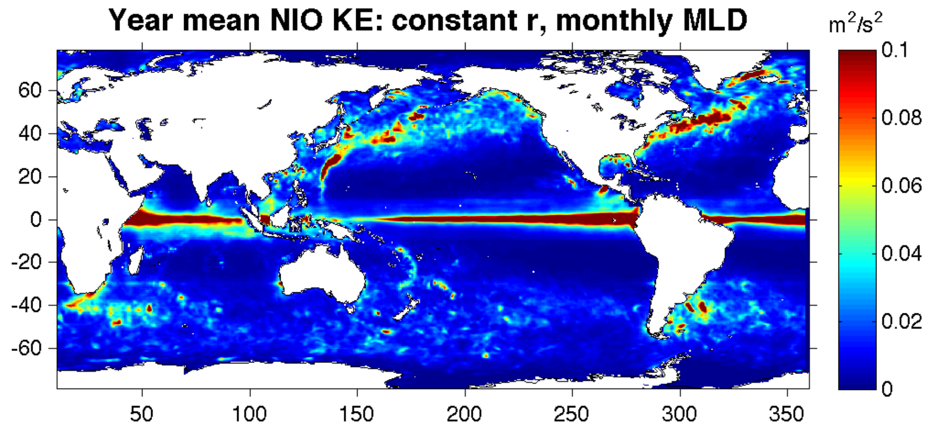
Slab Model Results Snapshot View of Speed

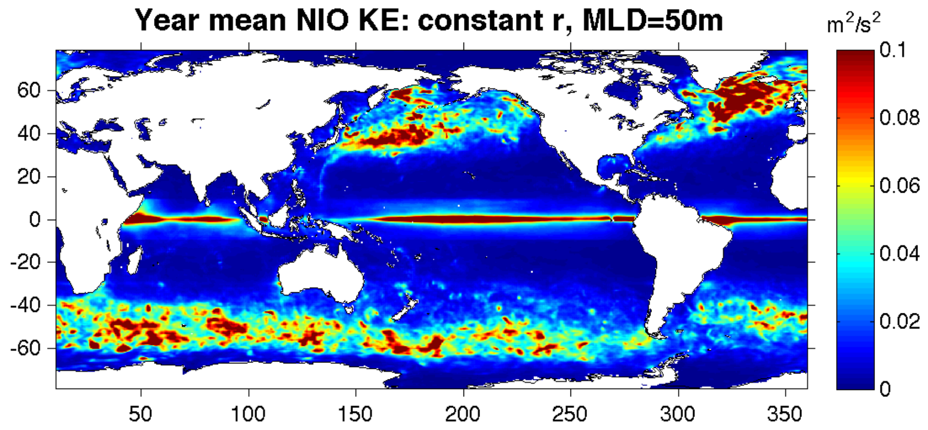


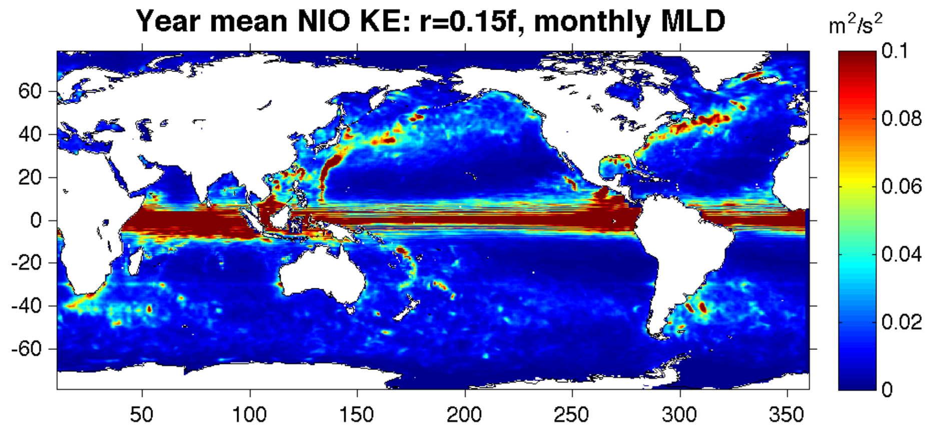




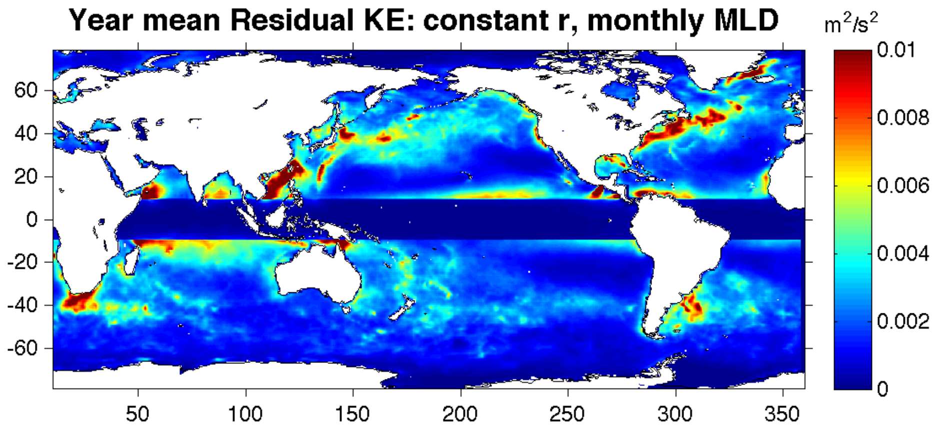
Energy in Near-Inertial Oscillations, Year Average

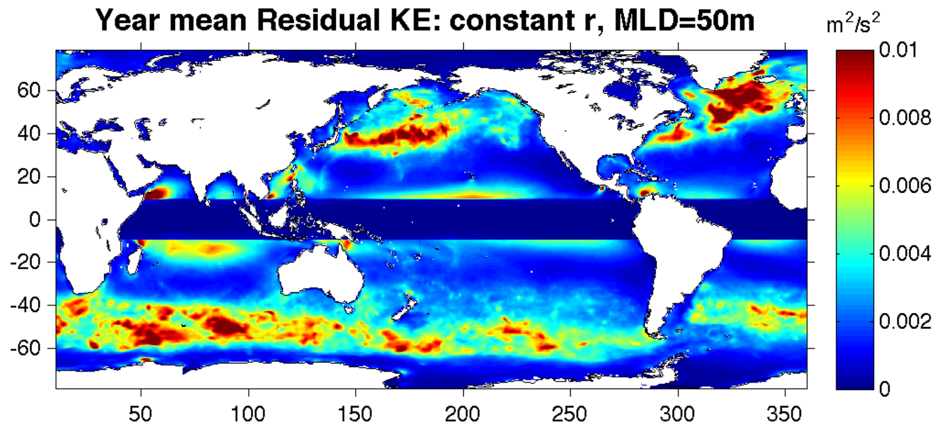


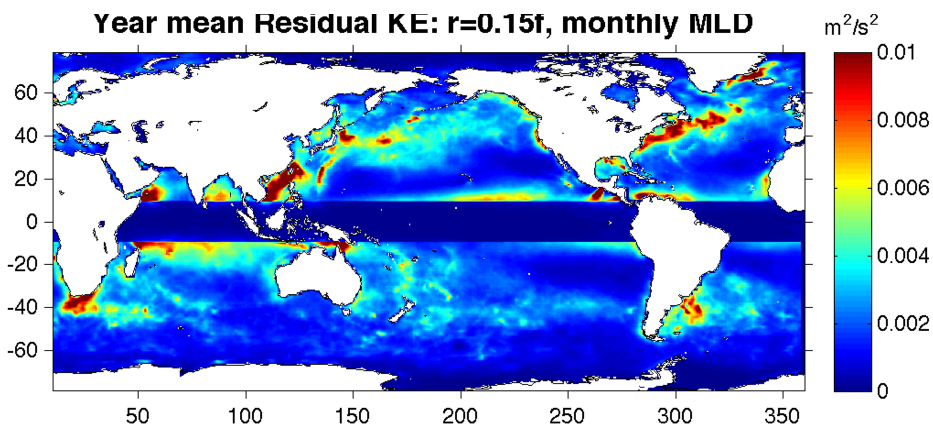




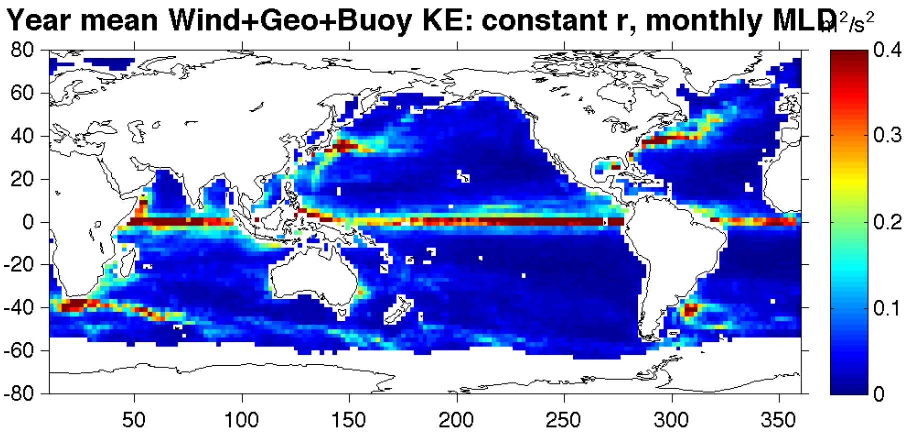
Energy in Residual from NIO, Year Average

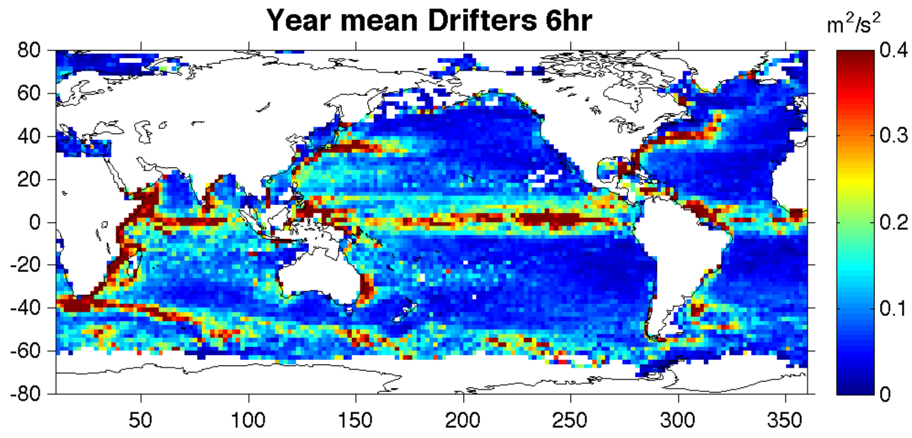


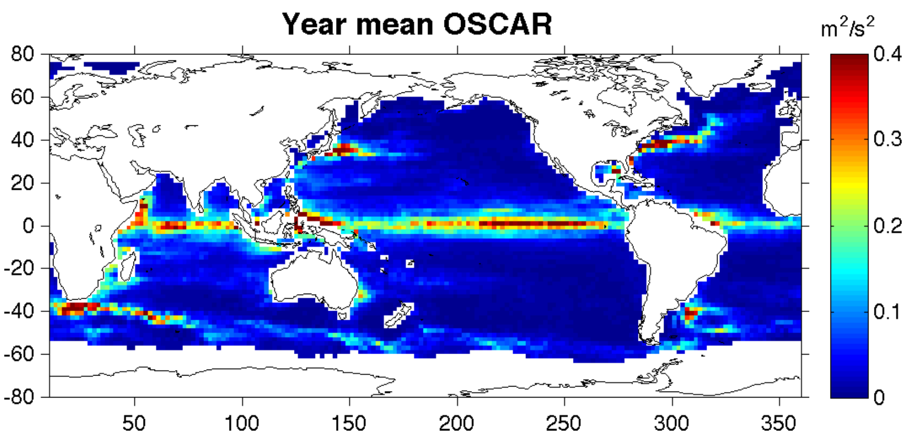


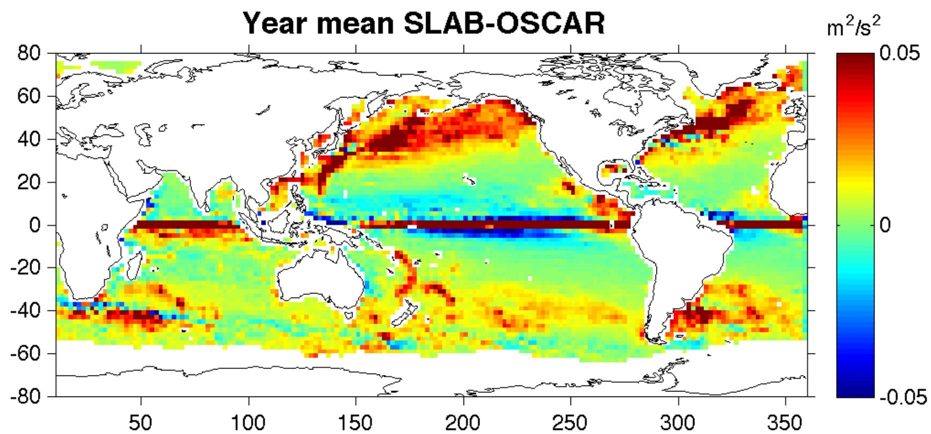


Comparison with Drifters









Parameterizations (for next year's meeting)

- So far,
  - No stratification, other than MLD
  - No transition layer
  - No surface fluxes
- Simplest inclusion: Price-Weller-Pinkel
  - Slab-model with shear-driven mixing at the base of the mixed layer
  - Convective mixing from surface fluxes
- More complicated, and very widely used: KPP
  - Empirical formulation originally based on atmospheric scalings
  - Convection, double diffusion, shear driven mixing, boundary layer…
  - Non-local K-profile diffusion based on large eddy penetration outside of boundary layer
- Turbulence closure
  - MY2.5, Kantha-Clayson ..
- And of course, these are just 1-D models … do I need the advection terms to get wind-driven OSCAR right?

Next Steps

- Slab model is promising using 6hr winds
  - More work to do in comparisons with drifters
    - Adequately separate inertial motions from fast wind-driven motions
    - Compare decay timescales between the two (work with J. Lilly)

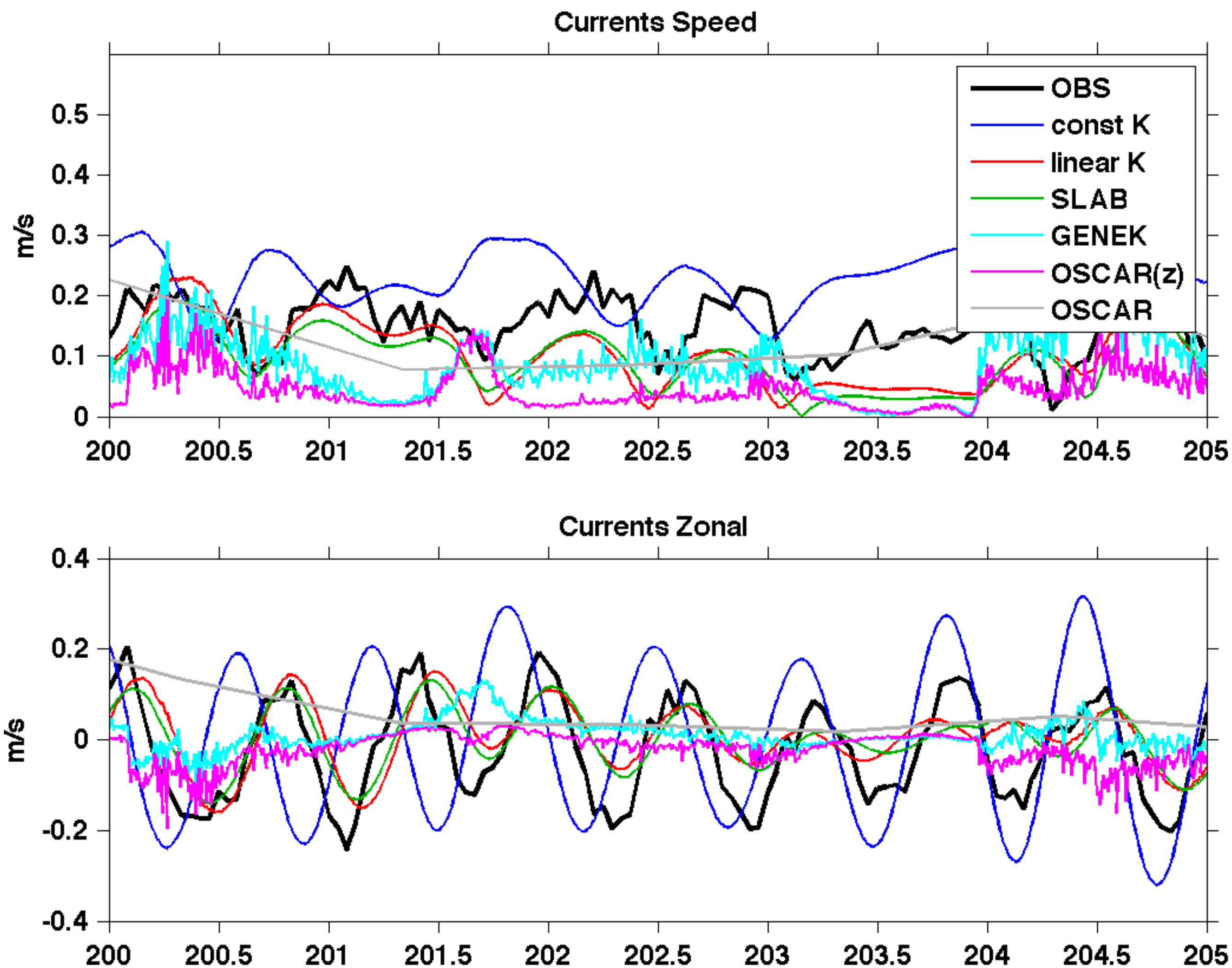
- Compare stress profiles with global buoys
  - Use Argo?

- Is it sufficient to use simple models, or do I need density profiles, surface inputs, transition layer mixing and nonlinear terms?

- Different goals:
  - Improve OSCAR 5-day (or 1-day) wind-driven currents
  - Study NIO generation, decay, using satellite-sensed fields
  - Isolate momentum transfer to test parameterization performance

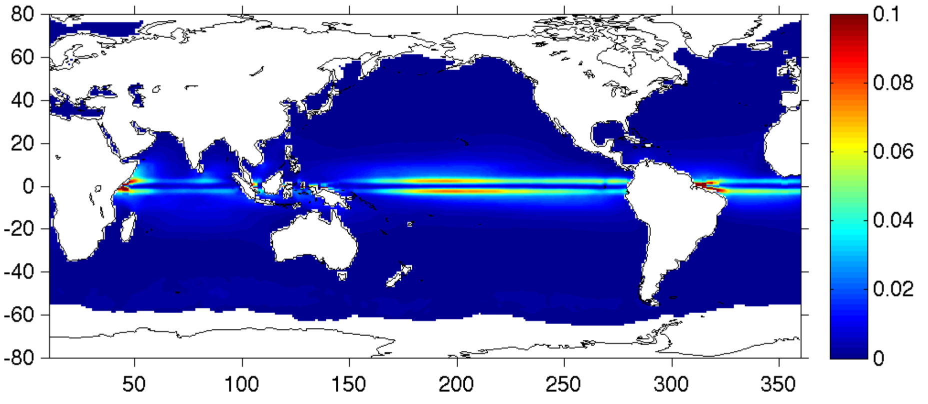
- Reminders:
  - SST fields- I need gradients (Dudley?)
  - Surface flux products (Lisan, Mark…?)

Model Performance for K(z) and d/dt

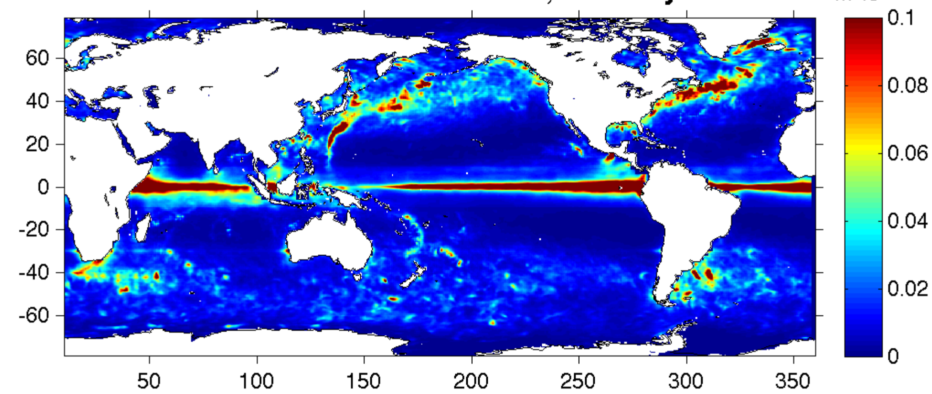


Energy in Currents, Year Average: OSCAR vs SLAB

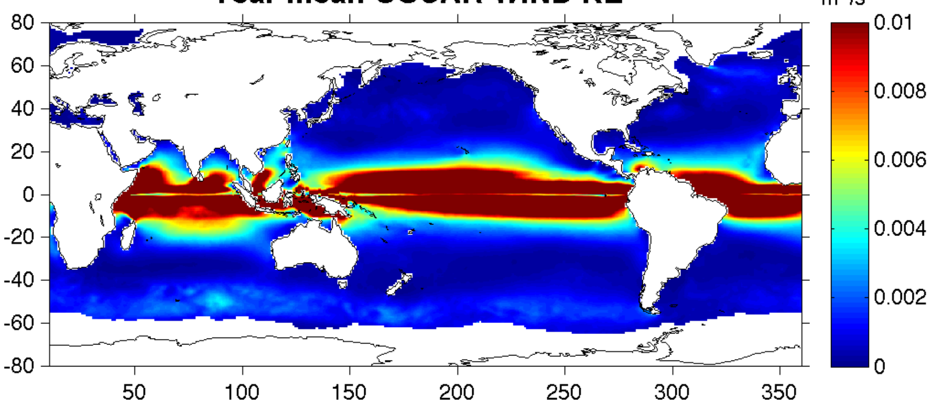
Year mean OSCAR WIND KE



Year mean NIO KE: constant r, monthly MLD



Year mean OSCAR WIND KE



Year mean Residual KE: constant r, monthly MLD